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Effect of amaranth residues (*Amaranthus hypochondriacus* L.) on weed control and yield or radish, onion and carrot

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Abstract

Studies were conducted to evaluate the effect of dry residue of amaranth (*Amaranthus hypochondriacus* L. var. Azteca) stem on weed growth and yield of radish (*Raphanus sativus* L. var. Champion), onion (*Allium cepa* L. var. Cambray), and carrot (*Daucus carota* L. var. Nantes), in order to determine the inhibitory effect of amaranth. The treatments were established under field conditions: 1) aqueous extract (AE); 2) soil-incorporated residue (S-IR); 3) surface-applied residue (S-AR); 4) unaltered soil control (U-S/C); 5) soil-incorporated control (S-I/C). The soil type at the study site was loamy-sand, with bulk density 1.47 m^{-3}, containing 2.1% organic matter. The species with the largest number of plants and highest dry weight in the three vegetables were *Simsia amplexicaulis* (Cav.) Pers., and a group of Gramineae grasses. Weed reduction was observed with treatments S-AR and S-IR related to the respective controls (U-S/C and S-I/C). Generally, decrease in plant number and dry weight in both treatments varied from 60% to 97% during the vegetable cycle. Radish yield decreased significantly with S-AR and S-IR; whereas that of onion and carrot increased significantly with S-AR. The results indicate that amaranth residue, incorporated or surface applied may control some weeds in radish, onion, and carrot. The surface-applied residue has potential to increase the yield of onion and carrot. However, it is necessary to find optimal residue management conditions for its application in the field to avoid reduction in yield of sensitive crops like radish, and/or when the residue is incorporated.

Additional key words: allelopathy; inhibitory effect; mulch; vegetable.

Resumen

Efecto de residuos de amaranto (*Amaranthus hypochondriacus* L.) en el control de maleza y rendimiento de rábano, cebolla y zanahoria

El estudio se realizó para evaluar el efecto del residuo seco del tallo de amaranto (*Amaranthus hypochondriacus* L. var. Azteca) en el crecimiento de maleza y el rendimiento de rábano (*Raphanus sativus* L. var. Champion), cebolla (*Allium cepa* L. var. Cambray) y zanahoria (*Daucus carota* L. var. Nantes), para determinar el efecto inhibitorio del amaranto. Los tratamientos se establecieron en condiciones de campo: 1) extracto acuoso (EA); 2) residuo incorporado en el suelo (RI); 3) aplicación superficial del residuo (RS); 4) testigo sin alteración del suelo (TE-S/AS); 5) testigo con incorporación del suelo (TE-C/IS). El tipo de suelo en el sitio de estudio fue arenoso-migajoso, con densidad aparente de 1,47 m^{-3} y 2,1% de materia orgánica. Las especies con mayor número de plantas y mayor peso seco en las tres hortalizas fueron *Simsia amplexicaulis* (Cav.) Pers., y un grupo de gramíneas. Se observó disminución de maleza con los tratamientos RS y RI en relación con los testigos respectivos (TE-S/AS y TE-C/IS). De manera general, la disminución del número de plantas y peso seco en ambos tratamientos varió de 60% a 97%, durante el ciclo de las hortalizas. El rendimiento de rábano disminuyó significativamente con RS y RI; el rendimiento de cebolla y zanahoria aumentó significativamente con RS. Los resultados indican que el residuo de amaranto, incorporado o aplicado superficialmente, puede controlar maleza en rábano, cebolla y zanahoria. El residuo aplicado superficialmente tiene potencial para incrementar el rendimiento de cebolla y zanahoria, sin embargo, es necesario encontrar condiciones óptimas del manejo del residuo para su aplicación en campo y para evitar que disminuya el rendimiento de cultivos sensibles como el de rábano y/o cuando el residuo es incorporado.

Palabras clave adicionales: alelopatía; cobertura; efecto inhibitorio; hortalizas.

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Abbreviations used: AE (aqueous extract); DAT (days after treatment); S-AR (surface-applied residue); S-I/C (soil-incorporated control); S-IR (soil-incorporated residue); U-S/C (unaltered soil control).

Introduction

The increase of weed species resistant to herbicides and of environmental problems like groundwater pollution because of synthetic herbicide use (Guzella *et al*., 2006), has led to designing integrated weed management strategies, or the discovery and development of new herbicides based on natural products (Sanyal *et al.,* 2008). These alternatives may reduce the need for herbicides. However, not everything in nature is healthy; many of the most toxic compounds known to humans are natural (*e.g.,* aflatoxin, fumonisins, ricin); but from a viewpoint of environmental toxicology, the relatively short half-life of most natural compounds in the field is desirable (Duke *et al*., 2002).

Allelopathy is included among the indicated alternatives, which is a concept defined and studied at length in the last decades and refers to any effect a plant may exert on another one by the production of chemical compounds that escape into the environment (Rice, 1984). This definition includes positive and negative effects. Several researchers report on the direct role of allelopathy in agriculture, and consider the effect of harvest residue decomposition on weeds and crop yield (Weston, 1996; Inderjit, 2002; Kruidhof *et al*., 2009).

Amaranth crop dates back to 5,000-7,000 years in America. The Mayas were probably the first to use it as a highly productive crop. Other people, like the Aztecs in the Valley of Mexico, learned to cultivate it (Becerra, 2000). Currently, amaranth is being reevaluated due to the high protein (15-18%), lysine, and calcium content of its grains (Tucker, 1986; Pedersen *et al.,* 1987; Petr *et al.,* 2003). Its leaves are consumed as a vegetable, with nutritional value comparable to spinach (Borneo and Aguirre, 2008). Amaranth is used as an ornamental plant, as forage, and has potential use in the cosmetic industry (O'Brien and Price, 1983). Its cultivation is gaining importance in the USA (Henderson *et al.,* 2000), and Canada (Gélinas and Seguin, 2008). In Mexico, amaranth crop is becoming important again, thanks to the preservation of its cultivation on a small scale by farmers, but its production has potential growth (Becerra, 2000) with a present area of 3,022 ha.

In the present study, the potential importance of amaranth in weed control is highlighted, but research to this regard is scarce. Several authors reported that the residues of some *Amaranthus* species might be efficient in weed control due to their allelopathic properties (Bradow and Connick, 1987; Menges, 1987; Connick *et al.,* 1989). Tejeda-Sartorius *et al.* (2004) and Tejeda-Sartorius and Rodríguez-González (2008) documented the inhibitory effect of aqueous extracts of *Amaranthus hypochondriacus* residue on some weeds and vegetable species by bioassays under laboratory conditions. Likewise, Tejeda-Sartorius *et al.* (2004) reported ferulic and *p*-cumaric as the principal contents of water-soluble phenolic acids in the aqueous extracts. Thus, *Amaranthus* may be an alternative to chemical weed control in vegetables. Economic feasibility of incorporating mulches in horticultural production has been studied, with the main objective of lowering input costs and reducing the application of pesticides and fertilizers (Lu *et al.,* 2000).

The present study contributes to generate safe alternatives to the environment decreasing the use of synthetic herbicides for weed control, and it was conducted to evaluate the effect of dry residue of amaranth (*Amaranthus hypochondriacus* L. var. Azteca) stems on weed growth and yield of radish (*Raphanus sativus* L. var. Champion), onion (*Allium cepa* L. var. Cambray), and carrot (*Daucus carota* L. var. Nantes), in order to determine the inhibitory effect of amaranth.

Material and methods

Location of the experiment and plant material

The study was carried out in the experimental fields of the Colegio de Postgraduados, Montecillo, Mexico, (19° 29' N and 98° 54' W, at 2,250 m above sea level, annual mean temperature of 15°C, and annual mean rainfall of 559 mm), under rainfed conditions. The soil type at the study site presented a bulk density of 1.47 m^{-3}, containing 2.1% organic matter. Nutrients had the following values: 0.09% N; 26 mg g^{-1} available P; 5 cmol kg^{-1} interchangeable K. The soil was classified based on Soil Taxonomy (Soil Survey Staff, 2006) as Typic Ustifluvents, with loamy-sand textural composition. During the experiment, the following environmental conditions prevailed: mean temperature varied between 14 and 18.4°C, the highest temperature between 21 and 26.4°C, and the minimum temperature fluctuated between 7 and 14.2°C, weekly mean data. Taking into account the sum of weekly data, total precipitation varied from 0 to 41.3 mm, and total evaporation ranged between 0 and 55 mm. Precipitation accumulated during the season was 217 mm.

Amaranthus hypochondriacus L. var. Azteca dry stem residue was tested after grain was harvested (leaves were previously removed from the stem). Thus, the amaranth residue was used as crop residue mulch, given that it was used as crop sub-product. The material was dried in a greenhouse and kept at 10% residual moisture, similar to that of any kind of straw used for forage. The plant material was ground (Standard Model No. 3 Wiley Mill) to pass a 2 mm mesh; afterwards it was stored in plastic bags stored at room temperature.

Treatments and experimental design

The treatments for assessing amaranth residue were: 1) aqueous extract (AE) applied to soil in 5 L m^{-2}; the extract was prepared with amaranth residue and distilled water in proportion 1:2.5 (v/v), using a 100 L container, manually shaken at 2 h intervals, during 20 min, until completing 45 h; the extract was filtered and applied to the field by sprinkler irrigation only once, without turning the soil over; 2) soil-incorporated residue (S-IR) at 5 kg m^{-2}; the residue was incorporated into a 20 cm-deep layer, similar to the conventional tillage system, using a spade; 3) surface-applied residue (S-AR) at 5 kg m^{-2}; 4) unaltered soil control (U-S/C), which was used to be compared with treatments AE and S-AR; 5) soil-incorporated control (S-I/C) means, like in treatment 2, that soil was incorporated into a 20 cm-deep layer, similar to the conventional tillage system, using a spade; this control was established to be compared with S-IR. Treatments with residue were applied 14 days before sowing the different vegetables in weed-free experimental units of 1 m^2. All vegetables were sown on June 12, 2002. They were arranged in a randomized complete block design with 4 replicates. Separated experiments for each vegetable were established (radish, onion, and carrot), at the same experimental site.

In order to analyze weed response to the treatments, samplings were made with the quadrant method (Mostacedo and Fredericksen, 2000). A quadrant of 0.25 m^2 was used and placed in the center of the experimental units where the aerial plant parts were manually harvested (all samplings were carried out in the same area). A first sampling was made 12 days after treatment (DAT) application, due to weed emergence in the treatments. After vegetable sowing, two samplings were made in radish (32 and 54 DAT), four in onion and carrot (32, 54, 89, and 110 DAT). Subsequent to each sampling, plants were separated and counted by species; and then dried in a forced air circulation stove at 60°C to assess their growth by dry weight.

The effect of the treatments was tested in radish var. Champion, onion var. Cambray and carrot var. Nantes. Vegetables were sown within the experimental units 14 DAT; in each of them, five sowing bands were arranged at the following densities: 6 g m^{-2} for radish and onion, and 1.8 g m^{-2} for carrot. Plant thinning was carried out leaving plants at a distance of 5, 10 and 15 cm, respectively, within the row; spacing between rows was 20 cm.

Study variables

Weeds

Weeds emerging naturally from the soil seed banks after application of treatments were collected, and the taxonomic identification of the species was done. The variables considered for weed analysis were «number of plants by species» and «dry weight».

Vegetable yield

Yield was considered as the fresh weight of the harvested parts of agricultural interest: hypocotyls for radish, bulbs for onion, and roots for carrot; for which all the plants of each experimental unit (g m^{-2}) were taken into account. Also, the harvest index (defined as yield product divided by complete plant biomass) of fresh weight was assessed.

Statistical analysis

In order to test the effect of the treatments on weeds measurement (number of plants and dry weight), a multivariate analysis of variance (MANOVA) was conducted for a design with repeated measures, based on the GLM procedure of SAS 9.1 (SAS, 2002). Transformation R^2 was carried out for getting plant count data, and to obtain dry weight data, logarithmic transformation was employed. In both cases, the results were very similar to the condition obtained without transforming the response variable; therefore the results are presented on the original scale. In order to determine the supposition of normalcy, the PROC UNIVARIATE program of SAS 9.1 (SAS, 2002) was used. Utilizing the Shapiro-Wilk test for the variables «number of plants» and «dry weight» per treatment, it was observed that in most cases the supposition of normalcy is reasonable. To analyze the effect of the treatments on vegetable yield, an analysis of variance (ANOVA) was used, and the differences among treatments were tested by means of a Tukey test (SAS, 2006) with $\alpha = 0.05$. Both weeds and yield metrics were analyzed independently for each vegetable.

Results

Weed species

The weed species that occurred during the cycle of the three vegetables were: *Simsia amplexicaulis* (Cav.) Pers. (Compositae or Asteraceae), a group of three grass species: *Eleusine indica* (L.) Gaertn, *Pennisetum clandestinum* Hochst. *ex* Chiov., *Cynodon dactylon* (L.) Pers. (Gramineae or Poaceae), as well as *Amaranthus hybridus* L. (Amaranthaceae), *Portulaca oleracea* L. (Portulacaceae) and *Malva parviflora* L. (Malvaceae). The following only grew in onion and carrot crops, because their cycle was longer, which allowed the establishment of other species in the growth season: *Chenopodium berlandieri* Moq. (Chenopodiaceae), *Brassica rapa* L. (Brassicaceae), *Verbena bipinnatifida* Nutt. (Verbenaceae), *Acalypha indica* L. (Euphorbiaceae), *Sonchus oleraceus* L. (Asteraceae), and *Galinsoga parviflora* Cav. (Asteraceae).

Simsia amplexicaulis and the group of Gramineae had the largest number of individuals and accumulated the largest amount of dry weight, thus the analysis of results was focused on them. The data for Gramineae is presented at the family level.

Weed community characteristics. Radish

Table 1 shows that there were significant differences among treatments throughout the sampling periods for the variables plant number and dry weight of *S. amplexicaulis*. Both variables were inferior in S-IR and S-AR treatments than the controls (S-I/C and U-S/C; Fig. 1). The following percentages of comparison in radish, and that in onion and carrot, represent the average of all sampling dates. Data in Tables 2 and 3 indicate a decrease in the mean plant number in S-IR by 93% (dry weight by 94%) with regard to S-I/C. In S-AR, plant number was reduced by 93% (dry weight by 97%) on average to that of U-S/C during full growth cycle.

For Gramineae, the MANOVA analysis did not indicate significant differences among treatments through the sampling periods for the variable number of plants, but there were significant differences in dry weight (Table 1). Both variables were reduced in the S-AR treatment compared to its control (U-S/C; Fig. 1), where mean dry weight was lower by 90% (Table 3). Gramineae plants did not emerge in S-I/C, in the period going from 12 to 32 DAT, but at 54 DAT dry weight was higher by 40% in S-I/C than in S-IR (Table 3).

Weed community characteristics. Onion

Significant differences among treatments for plant number and dry weight of *S. amplexicaulis* were obser-

Table 1. MANOVA analysis for plant number and dry weight of *Simsia amplexicaulis* and Gramineae in radish, onion, and carrot

Variable	Effects	F probability		
		Radish	Onion	Carrot
Plant number of *S. amplexicaulis*	Effect of sampling	0.0007	< 0.0001	< 0.0005
	Effect of interaction sampling*time	< 0.0018	< 0.0001	< 0.0007
Dry weight of *S. amplexicaulis*	Effect of sampling	0.0002	0.0021	0.0289
	Effect of interaction sampling*time	0.0021	0.0130	0.0608
Plant number of Gramineae	Effect of sampling	0.0593	< 0.0002	0.0077
	Effect of interaction sampling*time	0.5423	0.0364	0.0147
Dry weight of Gramineae	Effect of sampling	0.0003	< 0.0001	0.0089
	Effect of interaction sampling*time	0.0004	0.0289	0.2374

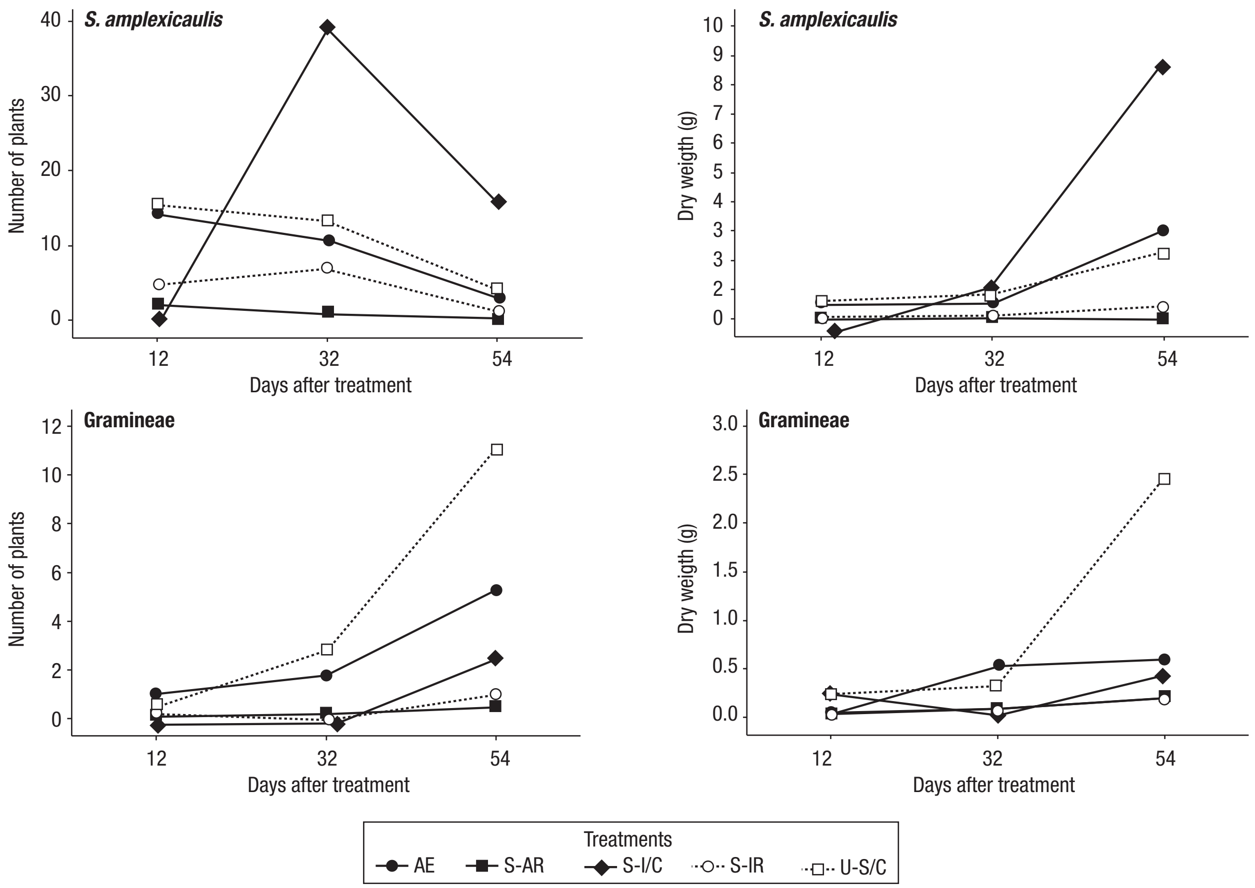

Figure 1. Mean plant number (per 0.25 m²) and dry weight (g) of *Simsia amplexicaulis* and Gramineae during cycle of radish with treatments: aqueous extract (AE); soil-incorporated residue (S-IR); surface-applied residue (S-AR); and controls: soil-incorporated control (S-I/C) and unaltered soil control (U-S/C).

ved in onion, with lower values in S-IR and S-AR than in S-I/C and U-S/C (Table 1, Fig. 2). In the samplings carried out in S-IR, the mean plant number was inferior to S-I/C by 79% (dry weight by 85%). In S-AR, average plant number of this species was 88% lower (87% in dry weight) than that of U-S/C (Tables 2 and 3).

In Gramineae, significant differences among treatments for variables plant number and dry weight were observed throughout the sampling periods (Table 1). In S-IR and S-AR treatments, those variables were lower than in S-I/C and U-S/C, especially at 54 DAT (Fig. 2). In S-AR, plant number was lower by 77% (dry weight by 84%), compared with the values in U-S/C (Tables 2 and 3).

Weed community characteristics. Carrot

In carrot, there were significant differences among treatments for the variable plant number of *S. amplexicaulis* throughout the sampling periods. Differences in dry weight were not observed (Table 1). In S-IR and S-AR lower values were maintained in number of plants and dry weight (Fig. 3). During the growth cycle, the average number of *S. amplexicaulis* plants in S-IR and S-AR was lower by 69% and 85% (85% and 96% in dry weight) than in S-I/C and U-S/C, respectively (Tables 2 and 3).

For Gramineae, the MANOVA analyses presented significant differences among treatments for plant number in the different sampling periods. Significant differences for dry weight were not found (Table 1). In Figure 3, it is generally observed that both variables maintained lower values in treatments S-IR and S-AR with regard to their controls during the different samplings. During the cycle, the average number of Gramineae plants in S-IR and S-AR was 65% and 73% lower than in S-I/C and U-S/C, respectively (Table 2).

In Figures 1, 2, and 3 it is observed that generally the AE treatment had similar behavior with re-

Table 2. Mean plant number of *Simsia amplexicaulis* (Cav.) Pers. and Gramineae (per 0.25 m^2) in crops of radish (*Raphanus sativus* L. var. Champion), onion (*Allium cepa* L. var. Cambray), and carrot (*Daucus carota* L. var. Nantes), in different samplings

Treatments	Radish		Onion		Carrot	
	S. amplexicaulis	Gramineae	*S. amplexicaulis*	Gramineae	*S. amplexicaulis*	Gramineae
12 days after treatment						
Aqueous extract	14.5	1.0	26.8	0.5	40.8	26.5
Surface-applied residue	2.0	0.0	0.8	0.3	0.0	0.0
Soil-incorporated residue	4.8	0.3	2.5	0.3	0.0	0.0
Unaltered soil control	15.5	0.5	30.0	2.5	42.0	13.3
Soil-incorporated control	0.0	0.0	0.0	0.0	2.8	0.0
32 days after treatment						
Aqueous extract	10.8	2.8	39.8	2.0	26.3	0.8
Surface-applied residue	1.0	0.5	0.8	1.3	0.0	1.3
Soil-incorporated residue	3.0	0.3	8.0	3.5	3.8	0.0
Unaltered soil control	13.3	1.8	34.8	4.0	38.0	6.8
Soil-incorporated control	39.3	0.0	98.0	3.3	77.8	0.3
54 days after treatment						
Aqueous extract	3.3	5.3	8.8	26.8	6.8	11.3
Surface-applied residue	0.0	0.5	0.3	6.8	0.0	1.3
Soil-incorporated residue	1.0	1.0	3.0	6.3	2.5	1.5
Unaltered soil control	3.8	11.0	6.8	28.8	8.5	17.8
Soil-incorporated control	15.8	2.5	12.0	6.5	5.3	12.3
89 days after treatment						
Aqueous extract			13.5	6.0	5.3	10.5
Surface-applied residue			1.8	1.0	1.8	0.8
Soil-incorporated residue			3.5	7.3	2.0	3.0
Unaltered soil control			7.0	4.0	7.8	6.3
Soil-incorporated control			12.0	6.5	5.0	8.3
110 days after treatment						
Aqueous extract			5.8	3.8	3.5	1.3
Surface-applied residue			0.8	2.3	1.8	0.8
Soil-incorporated residue			2.3	3.0	1.5	2.8
Unaltered soil control			4.3	5.8	3.5	3.8
Soil-incorporated control			2.0	3.3	2.3	3.0

gard to the control (U-S/C) in the three analyzed vegetables.

Vegetable yield

The yield of radish (hypocotyl fresh weight) decreased ($p < 0.05$) with the treatments S-IR and S-AR (Table 4). This is, the yield in S-AR was by 46% lower than that of U-S/C, whereas in S-IR it was 77% lower than in S-I/C. The harvest index decreased ($p < 0.05$) in S-IR compared to S-I/C. The yield of onion (bulb fresh weight) was statistically higher ($p < 0.05$) in S-AR (220%), related to U-S/C. In S-IR, yield was not significantly different ($p > 0.05$), like that of S-I/C. The yield of carrot (root fresh weight) was significantly higher ($p < 0.05$) in S-AR than in U-S/C. Yield was statistically equal ($p > 0.05$) between S-IR and S-I/C. No significant differences were observed for onion and carrot ($p > 0.05$) in the harvest index for these treatments.

The application of aqueous extract did not affect ($p > 0.05$) the yield, neither did the harvest index with regard to U-S/C in all three vegetables (Table 4).

Table 3. Mean dry weight of *Simsia amplexicaulis* and Gramineae (mg per quadrant of 0.25 m^2) in crops of radish, onion and carrot, in different samplings

Treatments	Radish		Onion		Carrot	
	S. amplexicaulis	Gramineae	*S. amplexicaulis*	Gramineae	*S. amplexicaulis*	Gramineae
12 days after treatment						
Aqueous extract	593	45	1,648	13	4,530	765
Surface-applied residue	25	0	5	5	0	0
Soil-incorporated residue	20	3	15	3	0	0
Unaltered soil control	565	228	1,460	58	4,150	765
Soil-incorporated control	0	0	0	0	35	0
32 days after treatment						
Aqueous extract	630	538	2,223	78	1,793	93
Surface-applied residue	38	63	465	130	0	438
Soil-incorporated residue	83	83	368	613	253	0
Unaltered soil control	755	313	1,840	1,035	3,393	1,905
Soil-incorporated control	1,025	0	4,750	665	4,620	20
54 days after treatment						
Aqueous extract	3,025	600	7,550	26,225	4,800	6,350
Surface-applied residue	0	225	50	2,225	0	75
Soil-incorporated residue	350	175	1,300	1,775	400	175
Unaltered soil control	2,225	2,450	3,850	26,950	11,925	49,575
Soil-incorporated control	8,650	425	5,100	12,250	3,625	7,525
89 days after treatment						
Aqueous extract			5,450	1,225	600	2,450
Surface-applied residue			300	425	400	150
Soil-incorporated residue			300	2,150	375	1,350
Unaltered soil control			1,675	3,775	2,275	1,400
Soil-incorporated control			2,775	3,700	700	1,125
110 days after treatment						
Aqueous extract			3,375	3,425	2,658	1,625
Surface-applied residue			450	2,600	38	125
Soil-incorporated residue			725	5,025	150	1,500
Unaltered soil control			2,125	6,825	4,500	2,500
Soil-incorporated control			650	3,525	2,075	825

Table 4. Yield (fresh weight; g m^{-2}) and harvest index of radish, onion, and carrot. Data mean of four replications. Different letters in the same column indicate differences with $\alpha = 0.05$

Treatments	Radish		Onion		Carrot	
	Hypocotyl	Harvest index	Bulb	Harvest index	Root	Harvest index
Aqueous extract	3,509^{bc}	0.75^{bc}	4,008^{b}	0.72^{a}	2,272^{b}	0.88^{a}
Surface-applied residue	3,049^{c}	0.83^{ab}	9,427^{a}	0.63^{a}	13,773^{a}	0.81^{a}
Soil-incorporated residue	1,589^{c}	0.75^{bc}	1,850^{b}	0.67^{a}	2,689^{b}	0.88^{a}
Unaltered soil control	5,633^{ab}	0.81^{abc}	2,929^{b}	0.62^{a}	2,560^{b}	0.77^{a}
Soil-incorporated control	6,833^{a}	0.85^{a}	4,738^{b}	0.59^{a}	1,456^{b}	0.87^{a}

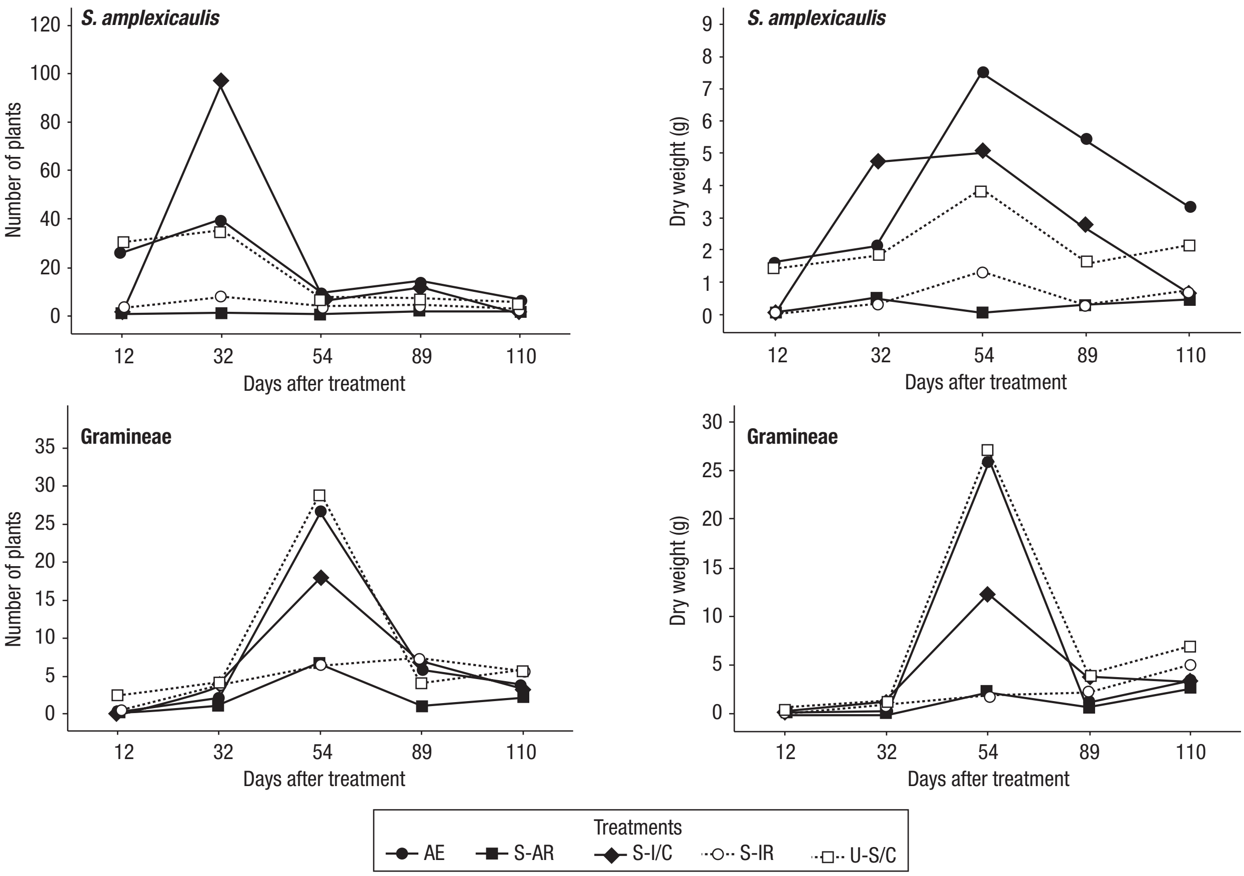

Figure 2. Mean plant number (per 0.25 m^2) and dry weight (g) of *Simsia amplexicaulis* and Gramineae during cycle of onion with treatments (see Fig. 1).

Discussion

Weed community characteristics

During the first weeks of the experiment, the weed species of greatest density was *S. amplexicaulis*, a broad-leafed species; subsequently, three gramineae species emerged (*E. indica*, *P. clandestinum*, *C. dactylon)*. The aforesaid agrees with Zimdahl (1993) who mentions that in modern agriculture dominance of species is usually presented by a few weed species (seldom by only one). This author also indicates that there are several species of weeds, some grasses among them, which germinate after a crop has been established; these species often germinate later than the broad-leafed ones, and then grow fast to compete with the crops. In the present study, this tendency was observed (in all three crops), since the largest number of *S. amplexicaulis* plants appeared at 32 DAT (although the highest gain of dry weight was obtained at 54 DAT), afterwards it decreased, which allowed the establishment of Gramineae, which had the largest number of plants and dry weight at 54 DAT. It is considered that the dry weight of the Gramineae group was an important component in the competition with vegetables.

In the control, where the soil was incorporated (S-I/C), there was no emergence of any species during the first two weeks, approximately, which may be related with indications of Harper (1977), who mentions that the seed bank in tillable land is continuously being moved and the soil profile turned upside down; seeds previously buried are brought to the surface, and those spread on the surface are buried. Also, certain weed species may be favored by crop management, but not others. Thus, some buried seeds might not germinate right away getting to the top of the soil, because they remained under conditions of dormancy, or weeds might not emerge before receiving rain. The aforesaid agrees with observations of the present study, since after the two weeks the largest number of *S. amplexicaulis* plants emerged (in all three vegetables).

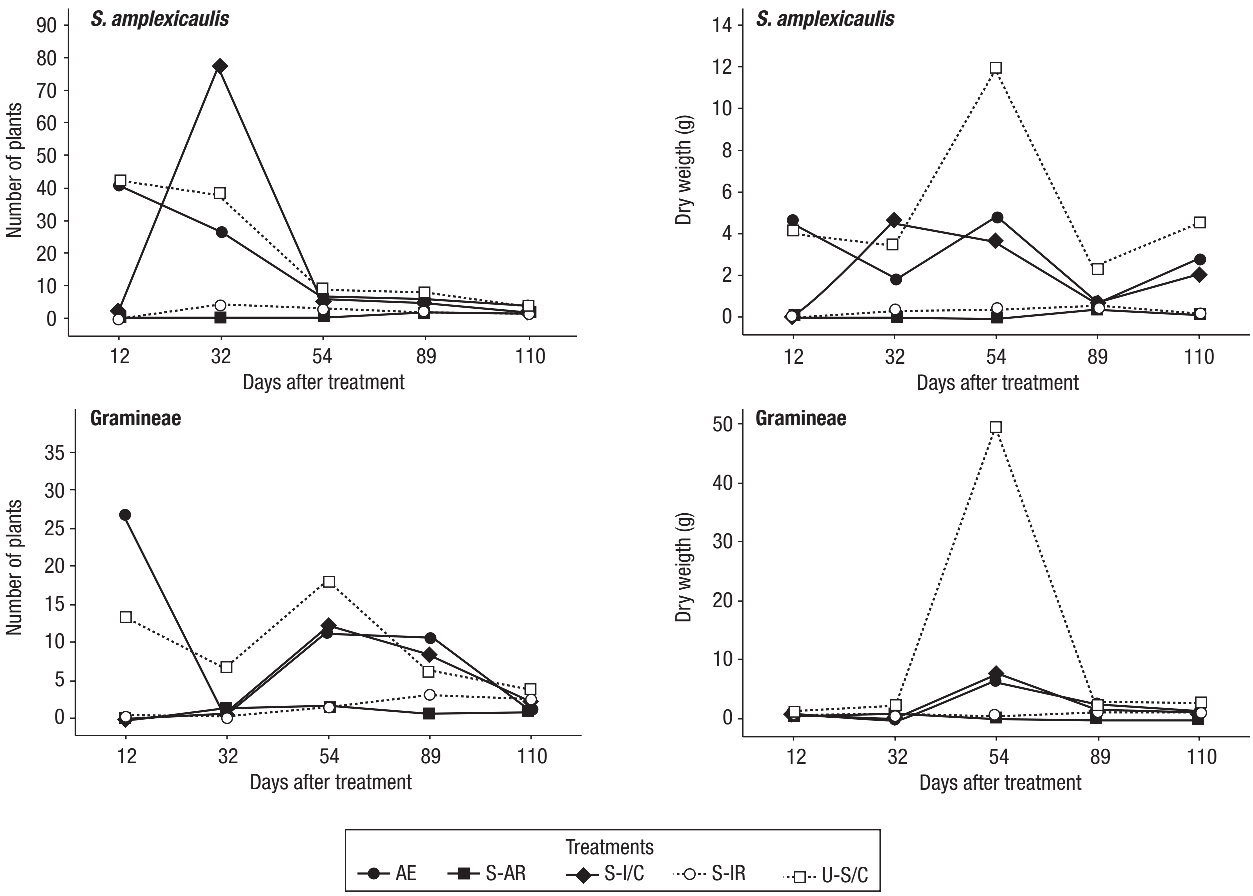

Figure 3. Mean plant number (per 0.25 m^2) and dry weight (g) of *Simsia amplexicaulis* and Gramineae during cycle of carrot with treatments (see Fig. 1).

Effect of the treatments on weed control

It was observed that surface application of the residue (S-AR treatment) and its incorporation (S-IR treatment) decreased weeds in all three vegetables; generally, this control was better appreciated in the higher growth period of weeds (32 DAT for *S. amplexicaulis* and 54 DAT for Gramineae). The effect of amaranth residue is similar to some studies reported for weed control in vegetables. Ngouajio *et al.* (2003) indicated that cowpea [*Vigna unguiculata* (L.) Walp.] mulch provided the greatest weed suppression over the 2 years of one experiment. The total number of weed seedlings that emerged from those plots varied between 45 and 60 plants m^{-2} and was significantly lower than the number from other cover crops treatments. Ngouajio and Mennan (2005) reported that cover crops of *Sorghum bicolor* (L.) × *S. sudanense* (P) Stapf., *Secale cereale* L., *Vicia villosa* Roth., may be used in integrated weed control of cucumber (*Cucumis sativus*), and complement other control methods, such as manual weeding and herbicides. Isik *et al.* (2009) pointed out that cover crops of winter crops like *Lolium multiflorum* L., *Secale cereale* L., *Triticum aestivum* L, and *Vicia villosa* Roth., reduce weed emergence in organic production of pepper (*Capsicum annuum* L.).

It is worth indicating that S-AR treatment promoted the highest control of weeds. Weston (1996) pointed out that crop residue covers can diminish weeds by their physical presence in soils as well as by releasing allelochemicals or microbially-altered allelochemicals. Teasdale and Mohler (2000) indicated that residue on the soil surface may influence the emergence of most plant species and that weed seedling emergence is more closely related to the natural barrier and light diminution under residues. Based on the results of the present research, the proportion of influence of each phenomenon cannot be stated (lack of light under residue and phytotoxic impact), but both are suggested, as there was not only a decrease of weed emergence, but also less weed growth, expressed in lower dry weight, which indicates probable assimilation of phytotoxic compounds, interfering with some growth process. Furthermore, the phytotoxic effect is also supported by weed control with residue incorporation. Bhowmik and Doll (1983) reported that the possible inhibitory effects of allelochemicals present in the residues of *Amaranthus retroflexus* and *Setaria glauca* may be related with the interference of photosynthesis and the biomass division in soybean and maize plants.

Treatment effect on yield of vegetables

Radish was the most susceptible of the three vegetables to the phytotoxic effect of amaranth residue. S-AR and S-IR treatments decreased its yield, S-IR being the one that showed the greatest negative effect. Before thinning, only about 30% of the radish plants emerged in S-IR compared to the control, and the emerging seedlings were less tall, the leaves showing yellowish-green coloring (data not presented). Therefore, it is considered that the initial phytotoxic concentration and the physical barrier established by surface application of amaranth residue interfered in critical moments of emergence and growth of radish, which is of short cycle, and this was reflected on the final yield. To improve this, delaying the sowing of this vegetable after having applied the treatments is suggested. Menges (1987) pointed out that it is better to delay commercial plantations of crops, susceptible to allelopathic inhibition of *A. palmeri,* until after 11 weeks. However, what happens with the time that residue phytotoxicity takes for the weeds? More analytic studies on persistence of these compounds are needed to determine the critical period of delay required for safe plantations (Menges, 1987). Likewise, in each case, the critical period of competition between weed and crop must be determined, because it contributes to establishing more sustainable weed management strategies (Sanyal *et al*., 2008).

Menges (1987) reported that *A. palmeri* residues incorporated in soil in amounts of 8.5 and 5.1 kg m^{-2} inhibited carrot growth by 49% and onion growth by 68%. In the present study, decrease of radish yield (77%) was found with residue incorporation of *A. hypochondriacus.* On the contrary, carrot yield was higher (84%) in S-IR in comparison with the control. Bhowmik and Doll (1982) pointed out that the possible reason of yield reductions by phytotoxicity of residues may be related with two possible mechanisms: allelochemicals directly leached from the residues or through microorganisms produced by their decay.

The increase of onion and carrot yield with S-AR shows the potential of amaranth as a mulch for stimulating vegetable yield. Leaching of inhibitory compounds of the residue may have allowed establishment of onion and carrot because these crops take more time for germination and their growth cycle is longer than that of radish. Other probable reasons for yield increase are: (i) nutrients; some authors report yield increase of vegetables such as lettuce and pepper due to the improvement of soil fertility, nitrogen fixing, increment of soil organic carbon, and mineralization and increase of nutrient availability in the plots where cover crops had been applied (Ngouajio *et al.,* 2003; Isik *et al.,* 2009); mulching has profound effects on soil fertility by helping maintain the fertile topsoil (Erestein, 2003). ii) moisture; mulching has a profound water conserving effect by reducing run-off and evaporative losses; therefore, more water is retained in the soil profile, where it remains potentially available for crop growth; mulching also reduces soil temperature oscillations (Erestein, 2003).

Besides the aforementioned, in the present paper the significant yield increase of onion and carrot at the surface application of residue, compared to its incorporation, may be related to the fact that the inhibitory compounds in the surface-applied residue are not getting into contact with the parts of agronomic interest, nor with the soil particles, at the same intensity as when the residue is incorporated. Foy and Inderjit (2001) suggest that, related to the inhibitory effect, the contact of allelochemicals with the plant roots is more important than the assimilation of allelochemicals.

The multiplicity of environmental factors under field conditions as well as the test material (donor plant) and the target plants, may produce results difficult to separate and to interpret, as some authors have pointed out (Weston, 1996; Inderjit, 2001). According to the number of questions asked about the role that the residue plays in plant health, it seems difficult to learn how to manage residues, maximizing crop production, controlling weeds by their allelopathic properties, and even improving soil characteristics to achieve higher productivity (Wuest and Skirvin, 1999). Regarding this, the work to be done with *Amaranthus hypochondriacus* is quite extensive to corroborate its allelopathic activity. It is suggested analyzing other doses of residue application, as well as establishing the necessary delay of sowing sensitive crops, such as radish. Likewise, further research based on bioassays under laboratory and greenhouse conditions is required in order to explain the results observed under field conditions with greater certainty, and include the effect on soil characteristics. For the time being, the present research is based on laboratory work by Tejeda-Sartorius *et al.* (2004), and Tejeda-Sartorius and Rodríguez-González (2008) which, added to the results of the present study, establishes important bases on the inhibitory potential of amaranth residue with regard to weed and its effect on yield of the analyzed vegetables.

Based on the experimental conditions established in the present study, the results allow concluding that amaranth residue, incorporated or surface-applied, decreases the number of plants and dry weight of the weed species *Simsia amplexicaulis* and Gramineae (*E. indica*, *P. clandestinum*, *C. dactylon*), in radish, onion and carrot. The most significant effect of amaranth residue on the indicated weed species is appreciated at 32 and 54 days after treatment application. Amaranth residues on the soil surface were most favorable for yields of onion and carrot, but the yield of radish was not favored by amaranth in any treatment. The results indicate that in amaranth residue there are substances inhibit growth of some weed species under field conditions; however, it is necessary to find optimal residue management conditions, as a natural herbicide for weed control without diminishing yield of sensitive crops like radish, and/or when the residue is incorporated.

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